

BROWSING JPEG IMAGES USING MPEG HARDWARE CHIPS

DESCRIPTION

BACKGROUND OF THE INVENTION

Field of the Invention

5 The present invention generally relates to data processing for the digital transmission, storage, retrieval and display of arbitrary images and, more particularly to the rapid decoding of images from digital data for presentation in potentially rapid
10 sequence.

Description of the Prior Art

15 Pictorial and graphics images contain extremely large amounts of data and, if digitized to allow transmission or processing by digital data processors and exploitation of various benefits of digital transmission, such as increased noise immunity and error recovery, often require many millions of bytes to represent respective pixels of the image or graphics with good fidelity. The sheer
20 quantity of data in images therefore presents a severe processing burden. However, pictorial data is often susceptible to substantial data compression without significant loss of image fidelity. That is, image data compression often allows
25 representation of images with less data in order to save storage costs or transmission time and costs with little or no perceptible effect on image fidelity.

The most effective compression is achieved by approximating the original image, rather than reproducing it exactly. The JPEG standard, discussed in detail in "JPEG Still Image Data Compression Standard" by Pennebaker and Mitchell, published by Van Nostrand Reinhold, 1993, which is hereby fully incorporated by reference, allows the interchange of images between diverse applications and provides the capability of producing digital 5 continuous-tone color images in multi-media 10 applications.

JPEG is primarily concerned with images that have two spatial dimensions, contain gray scale or color information, and possess no temporal 15 dependence, as distinguished from the MPEG (Moving Picture Experts Group) standard. JPEG compression can reduce the storage requirements by more than an order of magnitude and improve system response time in the process. A primary goal of the JPEG standard 20 is to provide the maximum image fidelity for a given volume of data and/or available transmission bandwidth or processing time and any arbitrary degree of data compression can be accommodated although, depending on image content, data 25 compression may be limited by loss of the image detail or features of interest. However, it is often the case that data compression by a factor of twenty or more (and reduction of transmission or processing time and storage capacity by a comparable 30 factor) will not produce artifacts which are noticeable to the average viewer.

The JPEG standard should be viewed as a family of compression techniques which have different properties and imply different advantages in regard

to hardware requirements, processing time and the like. Since maximum preservation of image fidelity relative to image data file size and the flexibility to customize compression techniques to exploit 5 characteristics of image content are principal goals of the JPEG standard, encoding and decoding may be computationally intensive and require significant amounts of time for a single image, particularly since JPEG coding and decoding is usually carried 10 out in software (since it is generally efficient to download the particular portion of JPEG corresponding to the image content with the image rather than to determine the particular JPEG family member with the properties best corresponding to 15 image and file content from resident software or hardware) and the higher speeds of special purpose chips are not generally available to most users. Therefore, the JPEG standard also allows various modes of operation such as are referred to as 20 sequential or progressive in order to more quickly present a portion of the image or the full image at reduced resolution (increasing over time), respectively, so that the image may be more quickly identified and processing terminated and begun on 25 another image if it is determined that a particular image is not of interest upon viewing of a partially decoded image. Iterating through a sequence of images is often referred to as browsing.

It can be appreciated that when a person may 30 wish to look through a group of hard-copy images, such as photographs, each image may be viewed for only a fraction of a second in order to find and/or select an image of interest. It is desirable to be able to provide a similar capability in displaying

images from digital data. Therefore, it has been the practice to use sequential or progressive operation of JPEG standard compression techniques to deliver an increasing fraction of the image at full 5 detail or the full image at increasing resolution so that an image which is not desired can be rejected as soon as it is recognizable by the viewer. However, software implementations of JPEG processing may not allow the frequency of image presentation to 10 be acceptably high consistent with providing images adequate for recognition.

The situation is somewhat different under the MPEG standard which must support image frame rates above the flicker fusion frequency of human visual 15 perception. To do so, additional compression is provided by exploiting data which remains constant between frames, image motion sensing and prediction for interpolation to reduce decoding demands and the like. The subject matter of the data for which MPEG 20 compression is used will also generally include long sequences of related images such as are presented in a motion picture which is marketed to subscribers. Therefore, the intended market economically supports the widespread availability of set-top boxes (STBs) 25 including special purpose data processing chips capable of very fast decoding and presentation of images.

However, MPEG decoders and the MPEG standard itself are not well-adapted to decoding of sequences 30 of independent images (even though independent "I-frame" images are periodically decoded, with intra-coded B-frames and P-frames between them, in accordance with the MPEG standard) and cannot be directly used for single images encoded under the

JPEG standard while preserving the detail and fidelity desired in single images. In fact, since the anticipated applications for JPEG and MPEG were quite different when those standards were 5 promulgated, incompatibilities between the coding techniques were tolerated such that transcoding from JPEG to MPEG data was not considered practical or even possible without unacceptable reduction of image quality even though MPEG to JPEG transcoding 10 was supported.

For example, so-called "oddification" (described at page 272 of "MPEG Video Compression Standard", published by Chapman & Hall, New York, N. Y., 1997, which is hereby fully incorporated by 15 reference) provided in the MPEG standard unavoidably leads to a reduction in image fidelity in any transcoding from JPEG to MPEG. Therefore, while economically justifiable, the utility of special purpose moving picture decoder chips and STBs is 20 quite limited relative to the amount of compressed digital image data and digitized and compressed libraries of images currently available and foreseeable.

Many libraries of images have been developed in 25 which rapid browsing is desirable. In addition to increased use of digital electronic cameras by individuals and which present many advantages over film cameras (not the least of which encourages the generation of increased numbers of images, many of 30 which may be later discarded and storage space reused), electronic files are being increasingly used to archive and provide rapid access to large quantities of documents, such as personal checks, negotiable certificates, legal records and the like.

Among such documents, a person may wish to browse images based on an arbitrarily located area such as check number or payee. The location of this information in the image may be inconsistent with progressive (since detail is not immediately available) or sequential (since the region of interest may not be near the top of the document) JPEG operation. Further, in such a case, the nature of the browsing done may require even less viewing time per image that can be conveniently allowed to determine that a particular image is not of interest.

In summary, while JPEG processing provides optimal single image quality for a given data volume, it is only widely available in software implementations that do not support desired image presentation frequencies for browsing or full image presentation or full resolution at presentation rates (or throughput in regard to, for example, decoding of a single image or several images which may each be very large) approaching those frequencies. Current applications do not economically support widespread availability of special purpose hardware to increase JPEG encoded image presentation speed notwithstanding the development of many libraries which would most desirably be accessed by browsing. Widely available MPEG hardware capable of suitably high image presentation frequency is not compatible with JPEG encoded data and, at the present state of the art, transcoding from JPEG to MPEG is considered to be impractical and to lead to unavoidable and generally unacceptable reduction in image fidelity, particularly if the transcoding process is lossy.

In this regard, transcoding of incompatible formats for lossless data compression is known. Figure 5-17 on page 77 of the above-incorporated JPEG text illustrates transcoding between the 5 Huffman and Arithmetic entropy coders for the JPEG standard. Converting the Group 3 facsimile standard into the better compressing Group 4 facsimile standard has been often done once the error recovering built into the Group 3 standard is not 10 needed (e.g. inside computer systems). Karl M. Marks, ("A JBIG-ABIC compression engine for digital document processing," IBM Journal of Research and Development, Vol42, No. 6 pp.753-758 (Nov. 1998)) describes a chip that can encode or decode the 15 bi-level image compression algorithms JBIG and ABIC. Thus conversion between them was made easy. The worst case for JBIG was not acceptable and so temporary storage of the documents converted into the ABIC version was preferred.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide for rapid browsing of digitally encoded images at presentation rates or throughput. 5 comparable to or exceeding rates for browsing of hard copy images such as photographs.

It is another object of the invention to provide a technique for transcoding JPEG data to a form which can be decoded by MPEG decoders without 10 significant loss of image fidelity.

It is a further object of the present invention to extend the utility of special purpose moving image decoder devices such as MPEG STBs to the decoding of high quality still images.

15 It is yet another object of the invention to browse within a JPEG image that contains many more pixels than the output device by shifting the field of view within the image, much in the manner of panning a camera.

20 In order to accomplish these and other objects of the invention, a method for improving decoding throughput of compressed image data is provided comprising steps of partially decompressing the compressed image data which is incompatible with a 25 hardware image decoder to form partially decompressed data in an intermediate code, recompressing the intermediate code in accordance with a compressed format compatible with the hardware image decoder to form recompressed image data, and decoding the recompressed image data with a hardware image decoder, whereby software 30 processing for decoding the compressed image data is reduced by hardware decoding of the recompressed

image data.

In accordance with another aspect of the invention, a method for viewing images is provided comprising steps of providing image data 5 representing a plurality of images in a first data format, transcoding data in the first data format to a second data format accommodated by a hardware decoder, decoding the data in the second format in parallel with transcoding data in the first format, 10 and substituting image data decoded from the data in the first format for image data decoded from the data in the second format after completion of the transcoding of data from the first format.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, aspects and advantages will be better understood from the following detailed description of a preferred embodiment of the invention with reference to the drawings, in which:

5 Figure 1 is a block diagram of a generalized and simplified JPEG decoder,

10 Figure 2 is a block diagram of a generalized and simplified MPEG I-frame decoder,

Figures 3A, 3B, 3C and 3D are block diagrams of browsing JPEG in a MPEG decoder chip in accordance with respective applications and embodiments of the invention,

15 Figure 4 is a schematic illustration of a JPEG packed block structure preferred for use in the invention,

20 Figure 5 is a high-level flow diagram of a preferred form of the transcoding process in accordance with the invention,

25 Figures 6A, 6B, 6C and 6D are flow diagrams of alternative techniques for determining the MPEG variable length code (VLC) table based on JPEG coded data including the define Huffman table (DHT) marker,

30 Figures 7A and 7B are flow diagrams of alternative techniques for Initializing MPEG chip hardware with and without creating an MPEG header, respectively,

Figure 8 is a flow diagram for entropy encoding of an MPEG slice of macroblocks shown in Figure 5,

Figure 9 is a more detailed flow diagram for the process of coding a macroblock included in

Figure 8,

Figure 10 is a detailed flow diagram of the process for entropy encoding of a block shown in Figure 9,

5 Figure 11 is a detailed flow diagram of the process for re-encoding the DC coefficient as shown in Figure 10

10 Figure 12 is a detailed flow diagram of a process for checking for ZRL codes as shown in Figure 10,

15 Figure 13 is a detailed flow diagram of a process for checking for E2 codes as shown in Figure 10,

20 Figures 14A and 14B are detailed flow diagrams of alternative processes for coding run-level VLC codes as shown in Figure 10,

25 Figure 15A, 15B and 15C are detailed flow diagrams of alternative processes for outputting VLC codes as shown in Figure 14A,

30 Figure 16 is a flow diagram for outputting escape, run and level codes as shown in Figures 14A and 14B,

35 Figure 17 is a flow diagram for converting JPEG extra bit codes to MPEG level codes as shown in Figure 16, and

40 Figures 18A and 18B are flow diagrams for checking the range of the level value for JPEG data and the general case, respectively, in the process shown in Figure 17.

DETAILED DESCRIPTION OF A PREFERRED
EMBODIMENT OF THE INVENTION

Referring now to the drawings, and more particularly to Figure 1, there is shown a block diagram of a generalized and simplified JPEG decoder 100. Figure 2 shows a similar depiction of a generalized and simplified MPEG I-frame decoder 200, for comparison. It should be understood that the 5 depictions of Figures 1 and 2 are arranged to convey an understanding of the concepts of the invention 10 and that no portion of either Figure is admitted to be prior art in regard to the present invention, particularly since the simplifications of the JPEG 15 and MPEG decoders depicted reflect the nature of the invention even though features of the invention are not included. While it is considered preferable by the inventors to implement the invention using the IBM PowerPC 401 processors embedded in some 20 commercially available MPEG chips, the invention and its underlying principles are, in fact, generalized and can be implemented with most commercially available MPEG chips.

It should also be understood that while the 25 invention will be discussed below in connection with the JPEG and MPEG standards, other standards exist and will be developed or at least proposed in the future to which the invention is similarly applicable, as will be understood by those skilled in the art since sufficient similarities will 30 necessarily exist between standards sufficient for application of the invention in order to support comparable performance to the JPEG and MPEG standards.

The JPEG decoder 100 of Figure 1 is basically of a pipeline architecture such that processes are performed in sequence on sequential groups of data. The JPEG compressed data stream is received at 110 and contains markers that identify and delineate the extent of the quantization tables and Huffman tables within the compressed data stream. The quantization tables are used by the dequantizer 130 and the Huffman tables are used by the entropy decoder 120.

5 (Entropy coding exploits the fact that the most common values represent a high degree of order and thus contain the least information and should be coded with the smallest number of bits while relatively rare values represent comparatively more

10 information and can be encoded with greater numbers of bits consistent with coding efficiency. More detailed discussions can be found in standard texts such as those incorporated by reference above.)

15

Once this data is in place, data corresponding to encoded macroblocks of the image are received, decoded and dequantized. Then, using the resulting values, an inverse orthogonal transform 140, usually an inverse discrete cosine transform (IDCT), is performed to regenerate image value data which corresponds to the image data which was previously compressed to JPEG format. This image data is then converted 150 to an RGB format or other format usable by a display 160 used to output the image to a viewer.

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30 The simplified and generalized MPEG I-frame decoder 200 of Figure 2 differs in significant ways from the JPEG decoder of Figure 1. As is known in the art, under the MPEG standard, different types of decoding are performed on different types of images

which are encoded and transmitted in different ways. I-frame images are independent of other frames and are transmitted in a form that reflects the entire image while other types of images, referred to as P-
5 frames which are approximated or predicted from preceding I-frames or P-frames, generally based on detected motion, and B-frames, which are bi-directionally interpolated from preceding and following I-frames and/or P-frames. Since there is
10 generally no temporal relationship between images in collections of images to be browsed, such as in image libraries alluded to above, it is assumed that compressed data received will be appropriate to an I-frame decoder 210 which would normally separate I-
15 frame compressed data from P-frame and B-frame compressed data. This I-frame compressed data is then received (as depicted at 220) and passed to an MPEG decoder 230.

Similarly to the entropy decoder 120 of JPEG decoder 100, the data is first entropy decoded at 240 and dequantized at 250. However, the MPEG standard now calls for oddification 260 which, as alluded to above, necessarily results in loss of image fidelity if JPEG to MPEG transcoding is
25 performed. Oddification is a process which adds error to the data to make round-off in all MPEG processes to occur in a consistent manner. Therefore, oddification inherently causes some loss of fidelity and, further, causes accumulation of error which may become substantial and significantly apparent. MPEG-1 and MPEG-2 standards call for different oddification techniques. So some MPEG
30 chips allow oddification to be optional as well as a selected one of those two oddification methods.

Then, as in the JPEG decoder of Figure 1, an inverse discrete cosine transform (IDCT) is performed at 270, conversion to RGB or other standard is performed at 280 and the resulting data is output to a display as indicated at 290. As is well-understood in the art, the MPEG standard and MPEG chips embodying it are strongly adapted for video display of a rapid succession of images and assumes a high degree of correlation between successive images for efficiency. These capabilities are, of course, of no significant utility in regard to still image data such as would be applied to a printer, particularly if uncorrelated, as generally would be the case. However, it has been recognized by the inventors that the reconstructed image data is accessible and could be applied to either a display or a printer or other image processing devices.

Elements/processes 240 - 290 are usually provided by circuitry integrated on a single chip as indicated by dashed line 230. Thus, it should be appreciated that the oddification process is essentially hard-wired into the integrated circuit of the MPEG chip. However, commercially available MPEG chips do not generally have a port or other structure which provides access to the IDCT portion of the chip 270 such that JPEG compressed data can be decoded to image data using the high speed special purpose processors which are included in MPEG chips and allowing the oddification process to be bypassed, as shown in Figure 3C.

This basic incompatibility can be better appreciated from Figures 3A and 3B illustrating two basic embodiments of the invention. Both of these Figures will be recognized as a combination of

Figures 1 and 2; including the processes of receiving JPEG data 110 and JPEG entropy decoding 120 prior to decoding with an MPEG decoder 230 with the oddification process bypassed in both 5 embodiments. The embodiment of Figure 3A also requires bypassing of the MPEG entropy decoder 240 while the embodiment of Figure 3B performs MPEG entropy encoding 310 followed by MPEG entropy decoding 240 in the MPEG decoder 230. That is, in 10 the embodiment of Figure 3A, the JPEG quantization values are used directly by the MPEG dequantizer 250 including the actual DC quantization value instead of the MPEG DC quantization by powers of two. In 15 the embodiment of Figure 3B, the quantized DCT coefficients are re-encoded using an MPEG Huffman table to be compatible with the MPEG entropy decoder 240. The MPEG entropy decoder 240 can then pass the quantized DCT coefficients to the MPEG dequantizer 250. In either case, the Figures show bypassing the 20 oddification process by disenabling it. However, there may be no hardware provision in commercially available MPEG decoders 230 for bypassing the oddification process 260 although some commercially 25 available MPEG chips (e.g. those produced by the assignee of the present invention) allow oddification to be disabled. If oddification cannot be bypassed, it is generally desirable to replace the lower quality image it causes within a short time (e.g. ten seconds or less) before the lower 30 quality is readily observed. It is known that the eye is distracted by motion and does not notice detail until an image is stable for a while. The replacement process is of relatively low visibility in such circumstances even if sequential and allows

the appearance of presentation of high quality images to be maintained consistent with a potentially high image presentation rate in accordance with the invention.

5 Additional differences in hardware provided between standard MPEG decoders and generalized JPEG processing and data involve the number of tables and sub-sampling arrangements that can be accommodated and which are assumed in the initial coding of the
10 JPEG data and hence constitute areas of incompatibility between JPEG data and MPEG hardware but which, as implemented in MPEG hardware, provide structure which, as the inventors have recognized, can be exploited in accordance with the invention
15 for JPEG decoding.

For example, The MPEG-1 standard only allows two tables for luminance and two chrominance components, respectively, while the JPEG standard allows four tables. For speed, some MPEG chips,
20 however, which accommodate the MPEG-2 standard, operate on two luminance blocks in parallel using two independent hardware tables and operate on the two chrominance components with two more tables. Thus three hardware tables may be provided in MPEG
25 chips and four hardware tables are provided in some MPEG chips. On the other hand, while the JPEG standard specifies four tables, it is often the case that only two or three are used since the fourth image value component is needed only for printing
30 (and would not be used for display, such as in browsing). The JPEG quantization tables found during parsing the JPEG data for Define Quantization Table (DQT) markers are loaded into the correct table positions. This can be done by creating the

MPEG-2 syntax. However, since this syntax is interpreted in the embedded processor of the MPEG chip, it is possible to load the tables without creating the MPEG-2 syntax. Therefore, the maximum 5 number of independent JPEG tables can be correctly handled by many MPEG chips and other MPEG chips are usually adequate for use in accordance with the invention since printing is not required in connection with browsing. Further, quantization is 10 constant in JPEG and quantization scaling from each table for each macroblock as provided in MPEG need not be used. In accordance with the invention, it is preferred to set the scale factor to 8 for all 15 quantization tables at the image slice level. If the chip does not handle the number of quantization tables, then the JPEG quantized coefficients can be (optionally) rescaled to allow a better approximation using the MPEG quantization table limits.

20 Also, differences are presented by image data organization between JPEG and MPEG. MPEG always operates on four blocks (generally 8x8 pixels each, representing a macroblock of 16x16 pixels) of luminance data with one, two or four blocks of 25 chrominance data while JPEG generally operates on four blocks of luminance data with one block each of Cr and Cb data although other options are provided as noted on pages 175 - 177 of the above incorporated Mitchell et al. text. In 30 this case, MPEG and JPEG order are compatible. If not, (about 98% of JPEG images on the web are subsampled 2:1 on both axes and thus MPEG covers JPEG requirements but the data is in a different order), it is possible to decode a sufficient amount

of JPEG data (e.g. two image block-rows) to re-
encode a slice of MPEG luminance blocks. MPEG chips
are commercially available with extended buffer
memory capacity which are preferred for practice of
5 the invention. In any case, suitable memory can be
provided for the conversion. Further, instead
of the JPEG run/size (RS) composite values as a
basis for the Huffman coding of the AC coefficients,
MPEG-1 and MPEG-2 have run/level symbols for the
10 more common combinations of runs and levels. The
less likely combinations in MPEG are encoded with
separate fixed length codes whereas JPEG provides no
such separate fixed length code but specifies all
possible codings in a single table. JPEG ZRL codes
15 (a run of more than fifteen zeros) must be merged
with the next RS symbols' run in converting to MPEG.

Yet another point of incompatibility of MPEG
hardware and JPEG data is that if the JPEG images
have a 4:4:4 (equal luminance and chrominance
20 dimensions), MPEG chrominance blocks are typically
2:1 subsampled in both coordinate directions.
Currently available MPEG-1 chips and some MPEG-2
chips do not support color conversion and display of
the 4:4:4 format that requires no sub-sampling in
25 both axes.

In summary, these points of incompatibility
prevent MPEG2 chips from being used to present JPEG
encoded images in rapid succession in a manner
suitable for browsing and other desirable
30 presentations such as for image comparison (e.g.
where the sequential or progressive JPEG
presentations may compromise the image memory of a
user or present an objectionable distraction. The
invention, in its broadest concept, reorganizes JPEG

data and available MPEG functions in a highly
interdependent and counter-intuitive manner,
preferably and advantageously using an intermediate
code format of packed form, incorporated by
5 reference and discussed below, to facilitate
transcoding to MPEG coding to allow existing chips
to rapidly process and present independent images in
rapid sequence without significant loss of image
fidelity.

10 The embedded processor is used to decode these
blocks into packed intermediate format which will be
described below. If the JPEG image is interleaved
baseline data this processing will automatically
entropy decode the related chrominance blocks into
15 packed intermediate format. Otherwise, the JPEG
compressed data is scanned for the chrominance
start-of-scans markers and the related chrominance
data separately entropy decoded into compressed
intermediate format. In other words, MPEG requires
20 luminance and chrominance to be interleaved in
macroblocks and does not allow separate compression
of luminance and chrominance.

25 The packed intermediate format is symbolically
illustrated in Figure 4 and is explained in detail
in U. S. Patent Application 09/736,444, filed
December 15, 2003, assigned to the assignee of the
present invention, which is hereby fully
incorporated by reference. As shown in Figure 4, in
30 the preferred enhanced packed intermediate format, N
(a byte) is the (even) number of shorts (byte pairs)
in the DCT block; FZKlast is the flag bits F (= 1 if
any S>8), Z (= 1 if ZRL is present) and Klast, the
six bit index of the last non-zero coefficient in
zig-zag scan order; DC (two bytes) is the DC

coefficient with the level shift included; [] indicates optional items in the block; ZRL is the zero run length symbol (0xF0) followed by another byte indicating 16, 32 or 48 zero coefficients; RS (a byte) is the JPEG Huffman symbol; E1 (a byte) is up to eight extra bits (left or right justified); E2 (a byte) is S-8 left justified extra bits if E1 is left justified and the eight least significant extra bits if E1 is right justified. EOB (0x00, a byte) is followed by one or three arbitrary bytes such that N is an even number. The technique of converting JPEG compressed data to this format is rapidly executed in a software efficient manner as discussed in detail in the above-incorporated U. S. Patent Application.

In this preferred packed intermediate format (a special case of the more generalized packed format of the above-incorporated application), the non-zero coefficients always fit into two or four bytes before entropy encoding or after entropy decoding. RS contains the four-bit run length of zero DCT coefficients and the four-bit size S which specifies how many extra bits are needed to determine the magnitude and sign of the coefficient. E1 contains up to eight extra bits. E2 is only needed if more than eight extra bits are used. For the case where ZRLs are present, for runs greater than fifteen zeros, the ZRLs are made to fit in two bytes rather than one, two or three bytes. The first byte is the ZRL symbol, 0xF0, (e.g. R = 5, S = 0, i.e. sixteen zeros) and the second byte is the run as a multiple of sixteen. The number of ZRL codes is in the high nibble of this second byte. The JPEG EOB symbol always terminates the valid data in the block and is

followed by one or three bytes to make the packed block fall onto a word boundary. Ensuring that necessary data is always fit into pairs of bytes in this manner simplifies and accelerates processing,
5 especially in software.

It should be recognized that the above described packed format or other data formats for partially decoded data suitable for use with the present invention are not necessarily MPEG compliant but only represent JPEG data which is placed in a form such that the data can thereafter be decoded by a MPEG chip with substantially the same efficiency and throughput as if the data were, in fact, MPEG compliant. It should also be recognized that the 10 usage of storage space generally required for MPEG image data is sufficient for high-resolution JPEG image data albeit used and allocated, in accordance with the invention, somewhat differently than in 15 MPEG processing. The conversion to a format acceptable by the chip is assisted by an embedded processor that has access to internal hardware 20 registers and busses.

It will be recognized by those skilled in the art in view of the above discussion, that the extra 25 bits might convert to a sign bit using the MPEG convention of $s=1$ for negative and 0 for positive. The remaining bits could be positive. This can be achieved by testing the sign bit and, if "1" changing only that bit to a "0". Otherwise, all of 30 the extra bits need to be inverted (e.g. by exclusive-OR operation).

In summary, the packed intermediate format provides for all information in JPEG encoded data to be represented in a compact form which has been

found to provide numerous advantages in enhancing decoding and other processing that has been found useful such as altering the dynamic range of the image data.

5 If the number of JPEG quantization tables exceeds the MPEG chip hardware capability or the MPEG DC quantization is limited to MPEG allowed values, then approximate conversion to the MPEG quantization can easily be accomplished during JPEG
10 entropy decoding into this packed format or as an independent process on the packed block row(s). Since JPEG allows enough tables for each component to have its own quantization table and MPEG-1 expects only one chrominance quantization table, one
15 or all of the components may need to be rescaled. Only the non-zero transform coefficients need to be converted. The MPEG coefficients will be the rounded values of the transform coefficients scaled by the ratio of the JPEG quantization to the MPEG
20 quantization for each color and position k in the zigzag scan order. The MPEG quantization values can be chosen to be powers of 2 to make the rescaling faster. Alternately, the rescaling results can be stored in a look up table(s) indexed by the JPEG
25 quantized coefficient. In some cases, the quantization may be close enough that the distortions are acceptable during browsing. However, then the replacement with the correctly decoded in software JPEG reconstructed image will
30 show a significant color/intensity shift. This choice can be left to the person browsing the images as to whether they prefer speed or better initial fidelity.

Figure 5 is a high level block diagram of the

steps which allow JPEG compressed images to be browsed using MPEG hardware by transcoding to an MPEG-2 slice in parallel with the software transcoding. This parallel processing allows the 5 MPEG chips to more than double the throughput of JPEG browsing by operating substantially autonomously from the software processor. Foreseeable processor and JPEG entropy decoder 10 improvements (depending on the amount of cache provided) may allow a four fold to ten fold increase in throughput since some MPEG processing is avoided in the processing of JPEG data in accordance with the invention. That is, with future foreseeable processor speeds, the software partial decoding of 15 JPEG becomes less of a limitation on overall throughput while substantial processing overhead is shifted to and accelerated by hardware MPEG chips providing a substantial speed advantage over software processing.

20 In Figure 5, the process steps illustrated each contain a plurality of processes briefly summarized by comments adjacent to the indicated process; some of which may be accomplished in alternative ways which will be discussed in detail in connection with 25 subsequent Figures. Step 510 begins with decoding of the JPEG header 511 which is described in detail in Chapter 7 of the above-incorporated Pennebaker et al. text and Annex B of the JPEG standard. Decoding of the JPEG header provides the JPEG parameters for 30 the image. This is followed by determination 512 of the variable length code (VLC) tables to use in the browsing process. MPEG-1 only has one VLC table (table 0), while MPEG-2 provides an additional table (table 1). No other VLC tables are provided or

allowed. The VLC tables are generally hard-wired into MPEG chips and the optimal table to be chosen is the table containing codes which are closer to the data of the image. Several strategies will be 5 discussed below in connection with Figures 6A - 6D. These tables combined into a single table for comparison are provided in table 10.26 in the above-incorporated Mitchell et al. text but are duplicated here as Table I for convenience. (Roman Numerals 10 will be used to reference tables in this description in order to avoid confusion with nomenclature for the VLC/Huffman tables therein, denoted by Arabic numerals.)

Table I - MPEG-2 VLC Tables

15 DCT AC coefficient table		VLC	VLC
run/level	table 0	table 1	
20	0/1	1s (first)	10s
	0/1	11s (next)	10s
	0/2	0100 s	110s
	0/3	0010 1s	0111 s
	0/4	0000 110s	1110 0s
	0/5	0010 0110 s	1110 1s
25	0/6	0010 0001 s	0001 01s
	0/7	0000 0010 10s	0001 00s
	0/8	0000 0001 1101 s	1111 011s
	0/9	0000 0001 1000 s	1111 100s
	0/10	0000 0001 0011 s	0010 0011 s
	0/11	0000 0001 0000 s	0010 0010 s
30	0/12	0000 0000 1101 0s	1111 1010 s
	0/13	0000 0000 1100 1s	1111 1011 s
	0/14	0000 0000 1100 0s	1111 1110 s
	0/15	0000 0000 1011 1s	1111 1111 s
	0/16	0000 0000 0111 11s	0000 0000 0111 11s
	0/17	0000 0000 0111 10s	0000 0000 0111 10s
35	0/18	0000 0000 0111 01s	0000 0000 0111 01s
	0/19	0000 0000 0111 00s	0000 0000 0111 00s
	0/20	0000 0000 0110 11s	0000 0000 0110 11s
	0/21	0000 0000 0110 10s	0000 0000 0110 10s

	0/22	0000 0000 0110 01s	0000 0000 0110 01s
	0/23	0000 0000 0110 00s	0000 0000 0110 00s
	0/24	0000 0000 0101 11s	0000 0000 0101 11s
	0/25	0000 0000 0101 10s	0000 0000 0101 10s
5	0/26	0000 0000 0101 01s	0000 0000 0101 01s
	0/27	0000 0000 0101 00s	0000 0000 0101 00s
	0/28	0000 0000 0100 11s	0000 0000 0100 11s
	0/29	0000 0000 0100 10s	0000 0000 0100 10s
	0/30	0000 0000 0100 01s	0000 0000 0100 01s
10	0/31	0000 0000 0100 00s	0000 0000 0100 00s
	0/32	0000 0000 0011 000s	0000 0000 0011 000s
	0/33	0000 0000 0010 111s	0000 0000 0010 111s
	0/34	0000 0000 0010 110s	0000 0000 0010 110s
	0/35	0000 0000 0010 101s	0000 0000 0010 101s
15	0/36	0000 0000 0010 100s	0000 0000 0010 100s
	0/37	0000 0000 0010 011s	0000 0000 0010 011s
	0/38	0000 0000 0010 010s	0000 0000 0010 010s
	0/39	0000 0000 0010 001s	0000 0000 0010 001s
	0/40	0000 0000 0010 000s	0000 0000 0010 000s
20	1/1	011s	010s
	1/2	0001 10s	0011 0s
	1/3	0010 0101 s	1111 001s
	1/4	0000 0011 00s	0010 0111 s
	1/5	0000 0001 1011 s	0010 0000 s
25	1/6	0000 0000 1011 0s	0000 0000 1011 0s
	1/7	0000 0000 1010 1s	0000 0000 1010 1s
	1/8	0000 0000 0011 111s	0000 0000 0011 111s
	1/9	0000 0000 0011 110s	0000 0000 0011 110s
	1/10	0000 0000 0011 101s	0000 0000 0011 101s
30	1/11	0000 0000 0011 100s	0000 0000 0011 100s
	1/12	0000 0000 0011 011s	0000 0000 0011 011s
	1/13	0000 0000 0011 010s	0000 0000 0011 010s
	1/14	0000 0000 0011 001s	0000 0000 0011 001s
	1/15	0000 0000 0001 0011 s	0000 0000 0001 0011 s
35	1/16	0000 0000 0001 0010 s	0000 0000 0001 0010 s
	1/17	0000 0000 0001 0001 s	0000 0000 0001 0001 s
	1/18	0000 0000 0001 0000 s	0000 0000 0001 0000 s
	2/1	0101 s	0010 1s
	2/2	0000 100s	0000 111s
40	2/3	0000 0010 11s	1111 1100 s
	2/4	0000 0001 0100 s	0000 0011 00s
	2/5	0000 0000 1010 0s	0000 0000 1010 0s
	3/1	0011 1s	0011 1s
45	3/2	0010 0100 s	0010 0110 s
	3/3	0000 0001 1100 s	0000 0001 1100 s
	3/4	0000 0000 1001 1s	0000 0000 1001 1s
	4/1	0011 0s	0001 10s
	4/2	0000 0011 11s	1111 1101 s
	4/3	0000 0001 0010 s	0000 0001 0010 s
50	5/1	0001 11s	0001 11s
	5/2	0000 0010 01s	0000 0010 0s
	5/3	0000 0000 1001 0s	0000 0000 1001 0s
	6/1	0001 01s	0000 110s
	6/2	0000 0001 1110 s	0000 0001 1110 s
55	6/3	0000 0000 0001 0100 s	0000 0000 0001 0100 s
	7/1	0001 00s	0000 100s
	7/2	0000 0001 0101 s	0000 0001 0101 s
	8/1	0000 111s	0000 101s
	8/2	0000 0001 0001 s	0000 0001 0001 s
60	9/1	0000 101s	1111 000s

	9/2	0000 0000 1000 1s	0000 0000 1000 1s
	10/1	0010 0111 s	1111 010s
	10/2	0000 0000 1000 0s	0000 0000 1000 0s
	11/1	0010 0011 s	0010 0001 s
5	11/2	0000 0000 0001 1010 s	0000 0000 0001 1010 s
	12/1	0010 0010 s	0010 0101 s
	12/2	0000 0000 0001 1001 s	0000 0000 0001 1001 s
	13/1	0010 0000 s	0010 0100 s
	13/2	0000 0000 0001 1000 s	0000 0000 0001 1000 s
10	14/1	0000 0011 10s	0000 0010 1s
	14/2	0000 0000 0001 0111 s	0000 0000 0001 0111 s
	15/1	0000 0011 01s	0000 0011 1s
	15/2	0000 0000 0001 0110 s	0000 0000 0001 0110 s
15	16/1	0000 0010 00s	0000 0011 01s
	16/2	0000 0000 0001 0101 s	0000 0000 0001 0101 s
	17/1	0000 0001 1111 s	0000 0001 1111 s
	18/1	0000 0001 1010 s	0000 0001 1010 s
	19/1	0000 0001 1001 s	0000 0001 1001 s
20	20/1	0000 0001 0111 s	0000 0001 0111 s
	21/1	0000 0001 0110 s	0000 0001 0110 s
	22/1	0000 0000 1111 1s	0000 0000 1111 1s
	23/1	0000 0000 1111 0s	0000 0000 1111 0s
	24/1	0000 0000 1110 1s	0000 0000 1110 1s
25	25/1	0000 0000 1110 0s	0000 0000 1110 0s
	26/1	0000 0000 1101 1s	0000 0000 1101 1s
	27/1	0000 0000 0001 1111 s	0000 0000 0001 1111 s
	28/1	0000 0000 0001 1110 s	0000 0000 0001 1110 s
	29/1	0000 0000 0001 1101 s	0000 0000 0001 1101 s
30	30/1	0000 0000 0001 1100 s	0000 0000 0001 1100 s
	31/1	0000 0000 0001 1011 s	0000 0000 0001 1011 s
	EOB	10	0110
	Escape	0000 01	0000 01

(s = sign bit)

In the above table, the first column gives the run of zero AC coefficients followed by the magnitude (level) of the non-zero coefficient. The second and third columns list the AC coefficient variable length code (VLC) words for table 0 and table 1, respectively. The sign bit is "0" for positive and "1" for negative (opposite to the convention for JPEG). The duplicate entry for run/level of 0/1 in table 0 only applies to predicted images and does not need to be considered further. Intra-coded images (e.g. independent I-images in MPEG terminology which do not utilize data from preceding or following images) always use the "11s" code. The escape code is used as a prefix before sending the actual run in six bits and the

level in twelve bits if the run/level combination is not in the table.

It should be noted that more than half the code words are identical between table 0 and table 1 and only a few have different numbers of bits which are listed in the following Table II.

Table II

JPEG R/S	run/ level	VLC table 0	VLC table 1	diff. (bits)	
10	0x00	EOB	10	0110	-2
	0x02	0/2	0100s	110s	+1
	0x02	0/3	00101s	0111s	+1
	0x03	0/4	0000110s	11100s	+2
	0x03	0/5	00100110s	11101s	+3
15	0x03	0/6	00100001s	000101s	+2
	0x03	0/7	00000001010s	000100s	+4
	0x04	0/8	000000011101s	1111011s	+5
	0x04	0/9	000000011000s	1111100s	+5
20	0x04	0/10	000000010011s	00100011s	+4
	0x04	0/11	000000010000s	00100010s	+4
	0x04	0/12	0000000011010s	11111010s	+5
	0x04	0/13	0000000011001s	11111011s	+5
	0x04	0/14	0000000011000s	11111110s	+5
	0x04	0/15	0000000010111s	11111111s	+5
25	0x12	1/2	000110s	00110s	+1
	0x12	1/3	00100101s	1111001s	+1
	0x13	1/4	0000001100s	00100111s	+2
	0x13	1/5	000000011011s	00100000s	0
	0x21	2/1	0101s	00101s	-1
30	0x22	2/3	0000001011s	11111100s	+2
	0x23	2/4	000000010100s	0000001100s	+2
	0x41	4/1	00110s	000110s	-1
	0x42	4/2	0000001111s	11111101s	+2
35	0x52	5/2	0000001001s	000000100s	+1
	0x61	6/1	000101s	0000110s	-1
	0x71	7/1	000100s	0000100s	-1
	0xA1	10/1	00100111s	1111010s	+1
	0xE1	14/1	0000001110s	000000101s	+1
	0xF1	15/1	0000001101s	000000111s	+1

40 The first column is the JPEG RS symbol under which the MPEG level falls. The last column shows the difference in number of bits (table 0 number of bits minus table 1 number of bits). For S>1, each RS symbol covers multiple levels. Table II only shows the combinations that appear in the MPEG tables. The "s" bit (sign) doubles the number of entries

represented in the table.

It is desirable to choose the VLC table to yield the lesser number of bits insofar as is possible for the JPEG compressed data of interest.

5 The following alternative strategies for performing this choice will now be explained in connection with Figures 6A - 6D. Figure 6A shows the unconditional choice of table 0 which is the only choice provided in MPEG-1 chips. Figure 6B illustrates the
10 additional alternative of selecting table 1 on the basis of the JPEG luminance Huffman table using more than three bits for the EOB code. That is, if EOB codes are very frequent (e.g. about 1/4 of the codes) to justify a two-bit code, VLC table 0 is
15 probably optimal notwithstanding that other codes are thus forced to greater numbers of bits since the amount of image data is necessarily relatively small. Conversely, relatively infrequent EOB codes (e.g. about 1/16 of the codes) infers significantly
20 more image data which can be expressed in fewer bits according to VLC Table 1. Figure 6C illustrates basing the choice of table on whether or not the compression ratio is good in accordance with a rationale similar to that discussed in regard to
25 Figure 6B. Figure 6D assumes a custom table and provides for its use by calculating the number of bits based on the Define Huffman Table (DHT) marker. The process of Figure 6D will estimate accurately which table will produce less bits. Since most of
30 the MPEG code words have the same lengths in table 0 and table 1, only those code words which have a differing number of bits need be considered in the calculation.

Table III gives a summary of the average

difference in bits for each of the RS symbols. Only RS symbols with $S < 5$ and runs of 15 or less need be considered. Scaling up the table entries by 4 will convert the floating point numbers to integers. In Table III a '.' represents zero difference of bits and indicates that the tables have the same coding efficiency. Otherwise, negative numbers favor VLC table 0 and positive numbers favor VLC table 1 for optimal transcoding efficiency (e.g. average over the symbols of that size and relative frequency of occurrence wherein all symbols of a given size are equally likely to appear.

Table III. Summary of the average difference (bits) for the levels corresponding to each RS symbol.

		S				
		0	1	2	3	4
20	0	-2	.	+1	+3	+4.75
	1	.	.	+1	+1.5	.
	2	.	-1	+1	+0.5	.
	3	.	.	.	.	.
	4	.	-1	+2	.	.
	5	.	.	+0.5	.	.
	6	.	-1	.	.	.
	R	.	-1	.	.	.
	7	.	-1	.	.	.
	8	.	.	.	.	.
30	9	.	.	.	.	.
	A	.	+1	.	.	.
	B	.	.	.	.	.
	C	.	.	.	.	.
	D	.	.	.	.	.
	E	.	+1	.	.	.
35	F	.	+1	.	.	.

A methodology for estimating the bits is given

below where i indexes into the JPEG AC RS table for each given component (e.g. color = 0, 1, 2 which are arbitrary numbers). This pseudo-code assumes a table difference "diff" containing the last four columns of Table III multiplied by 4. (Column S = 0 contains only the EOB value and need not be further considered.)

```

      sum = 0          /* clear total bits      */
10     do color=0 to 2; /* for Y, Cb, Cr      */
        bits = 0        /* clear bits estimate */
        num=0x10000    /* start with 2**17    */
        i=0            /* start at first RS   */
        do j=1 to 16   /* loop for 16 lengths */
          if L(j) > 0  /* if codes of L bits */
            do k=1 to L(j) /* loop for number in L */
              tem=RS(i)  /* load next RS symbol */
              i=i+1        /* increment index      */
              if tem=0      /* if EOB               */
                bits=bits-num<<3 /* EOB weighted by -8 */
20            else        /* else not EOB        */
              S=0x0F AND tem /* isolate S           */
              if S<5        /* if small S           */
                S=S-1        /* range 1-4 in 2 bits */
                R=tem >> 4   /* isolate run          */
                n=(R<<2)+S  /* calculate index      */
                bits=bits+num*diff(n) /* add number*diff */
              endif         /* end if small S      */
              endif         /* end else not EOB    */
            enddo          /* end k loop          */
          endif         /* end if L(j) > 0      */
          num=num >> 1   /* cut number in half   */
        enddo          /* end loop for 16      */
        sum= sum + H(color)*v(color)*bits /*weight by blocks*/
      end

```

35 where H and V are the number of relative number of blocks horizontally and vertically between the components in the JPEG image.

40 If the sum is negative, table 0 is selected. Otherwise table 1 is selected. When the JPEG image only has luminance, the loop is only done for luminance and $(-8*0x10000>>1)$ is added to the sum. The chrominance blocks required by MPEG, but which may not exist for a given image, are recreated as 100% EOB symbols, but there are only half as many chrominance blocks as luminance blocks. A more

sophisticated formula could weight the differences for smaller magnitudes more in calculating the average for each RS symbol.

Another alternate embodiment is practical if
5 the JPEG compressed data has been previously
transcoded or the calculation is done during the
entropy decoding of the entire JPEG image into
intermediate format. In this alternate embodiment
the actual occurrence of RS symbols is used to
10 compute which table would give the shortest MPEG
compressed data.

Referring again briefly to Figure 5, having
completed determination of the MPEG VLC table to be
used, the next step is to initialize (513) the MPEG
15 hardware, either directly or by syntax. Two
alternative methods of doing so are illustrated in
the flow charts of Figures 7A and 7B. The first
(Figure 7A) generates an MPEG header with correct
syntax. The second (Figure 7B, designated 513')
20 directly sets the hardware. Because the partial
software decompression (e.g. entropy decoding) may
be done with knowledge of the target hardware
decoder, advantage can be taken of special
information about the target hardware such as not
25 generating a true header but simply loading the
appropriate variables into registers.

Returning now to Figure 5, step 510 is
completed by using the correct JPEG quantization
table (Q-table) for each component (e.g. luminance
30 and chrominance). MPEG-1 traditionally requires the
DC quantization value to be identically 8. MPEG-2
allows the DC quantization to be 8, 4 or 2. If
possible, the true DC quantization should be used.
If not possible, then the required value of 8 will

distort the image unless a correction of the DC values is made to compensate for this hardware inflexibility. The rescaling is straightforward for the DC coefficient since the quantization for the 5 MPEG DC is a power of two (e.g. 8, 4, 2). So the product of the JPEG DC quantization and the DC coefficient can be taken and then the result optionally rounded by adding half the MPEG quantization value before shifting right 3, 2, or 1. 10 Alternately, a lookup table could precompute the rescaled quantized DC coefficients for each color component. Then, such correction is likely to lead to some distortion in the final decompressed image. If another image is not promptly decoded and 15 substituted, the software can slowly substitute a properly decoded image from the original compressed data while the distortion in the data rapidly decoded in accordance with the invention may or may not be noticeable at the presentation rates possibly 20 encountered during browsing. Preferably, if possible, the IDCT oddification may optionally be disabled to reconstruct an image closer to that which would be decoded by normal (JPEG) software decoding. In any case, the image as decoded by 25 normal software decoding may be substituted if the image presentation rate allows. At faster browsing rates, the fidelity of the image presented will be of relatively less importance to a user. Finally, the slice counter is initialized to zero. 30 Having completed the setup of the MPEG-2 chip hardware 510, it is determined from the decoded JPEG header if the associated JPEG data is interleaved at 520 of Figure 5. If the data is interleaved, two luminance block rows of the data are entropy decoded

to an intermediate format, preferably the packed intermediate format as discussed above with reference to the above-incorporated Patent Application. In addition, the chrominance 5 corresponding chrominance blocks must also be decoded to the packed intermediate format.

If the number of Chrominance blocks corresponding to the four luminance blocks of an 10 MPEG macroblock exceeds the capacity of the hardware (e.g. only accepts MPEG-1 data which has one chrominance block of each color component per macroblock), fast techniques for converting multiple blocks into a single block in the transform domain are disclosed in U. S. Patent Application 15 (Attorney's Docket No. BLD9-1999-0042) which is hereby fully incorporated by reference.

If the data is not interleaved, two luminance (2Y) block rows and associated chrominance (e.g. Cb and Cr) are entropy decoded. This provides image 20 data which can be re-encoded as a MPEG slice of macroblocks and removes a significant compatibility issue between JPEG and MPEG discussed above. This MPEG entropy encoding can be performed rapidly because of the packed format. As above, the number 25 of chrominance blocks per macroblock may need to be adjusted.

Under JPEG, the components can be sub-sampled over a range of 1 to 4, horizontally and/or 30 vertically. If the chrominance image component is not subsampled vertically by 2:1, latency to collect data for an MPEG slice is increased compared with JPEG. An extra block-row of luminance data must be entropy decoded before the macroblock re-encoding can be initiated, and then re-encoding can be

conducted concurrently with the decoding of the following block-row. This requires additional memory (which is available in commercial MPEG chips) but at most latency is a very small fraction of the 5 image processing time since it corresponds, at most, to an MPEG slice.

Once the MPEG slice has been entropy encoded, the encoded slice data can be passed to the MPEG hardware chip and the current slice number 10 incremented as shown at 530. The process then loops to 520 of Figure 5 for decoding and re-encoding of the next slice in accordance with the MPEG data format.

An exemplary and preferred methodology for 15 performing the processes summarized above in regard to step 530 of Figure 5 will now be described in greater and increasing detail in Figures 8 - 18. It should be noted that Figure 9 details a step 820 in Figure 8, Figures 11 - 14A and 14B detail respective 20 processes and alternatives 1020, 1041, 1043, 1044 and 1044' in Figure 10, Figures 15A - 15C are alternative processes to perform process 1430 of Figure 14, Figure 16 details process 1440 of Figure 14, Figure 17 details a process 1610 of Figure 16 25 and Figure 18 details a process 1731 of Figure 17. These cross-references are noted in the respective Figures.

It should be noted that the processes as broken 30 down for purposes of explanation in Figures 8 - 18 generally follow processes available in commercially available MPEG chips, as will be readily understood by those skilled in the art. Where particular strategies are preferred or may yield enhanced performance in available control of certain

processes, these strategies will be described in detail. Otherwise, relatively brief description of these processes will be sufficient for those skilled in the art to successfully practice the invention.

5 Page references in the drawings are to the above incorporated MPEG Video Compression Standard.

10 MPEG-2 requires a slice header to precede each macroblock row and care must be taken to follow this convention as required by the hardware. To entropy encode an MPEG slice of macroblocks, it is necessary to re-encode an inter-block row with variable length codes (VLCs). Therefore, as shown in Figure 8, step 810 initializes the MPEG2 chip hardware for the next slice by setting all the color DC predictions
15 (Pred(Y), Pred(Cr), Pred(Cb)) to zero to correspond to the JPEG level shift of the DC coefficient. To answer a point of incompatibility between MPEG and JPEG noted above, the DC coefficient of the transform data must be appropriately compensated.
20 Then, a macroblock may be re-encoded as indicated at 820, as detailed in Figure 9, looping to re-encode all the macroblocks in a slice. The looping for each sequential macroblock in a slice also reformats the order of data to reconcile JPEG and MPEG
25 formats.

30 Referring now to Figure 9, the re-encoding of a macroblock is performed by first encoding the macroblock header by setting the macroblock address increment and the macroblock type (intra-only to indicate no prediction from previous or future images). The block counter is then initialized to zero as shown at 910. Figure 10 details the following process which outputs MPEG VLCs and increments the block counter. The process then

loops for each (e.g. 8x8) block in the (e.g. 16x16) macroblock; further reconciling the JPEG and MPEG data formats.

5 The MPEG entropy re-encoding process for a block begins with initialization 1010 which includes loading N and FZKlast from the packed intermediate code, flags for $s>8$ (F) and input ZRL(s), and the DC coefficient. The input index, $i=3$ is then set. The re-encoding step 1020 is detailed in Figure 11, as 10 will now be discussed.

15 Referring now to Figure 11, a DC coefficient, diff, is predicted and saved as a prediction at step 1110. If rescaling of the quantized DC coefficient is necessary and has not been done during JPEG entropy decoding, the variable tem which contains the DC coefficient can be rescaled before the first step in 1110. Then, if $j<4$, which has been set and incremented as shown in Figure 9 (the first four blocks being thus guaranteed to be luminance data), 20 the value is a luminance DC value and a luminance code is derived from a table corresponding to table 10.24 in the above-incorporated MPEG Video Compression standard, as illustrated at 1130. If not, the value is a DC chrominance value and a 25 chrominance code is derived from a table corresponding to table 10.25 of the same above-incorporated reference. The result, in either case (in accordance with the value of j) is then tested at 1150 and, if diff=0 no additional bits need be 30 considered and outputting more bits may be skipped and the process of Figure 11 is complete. If not, Diff is again tested at 1160 and, if positive, decrementing can be skipped and the differential DC coefficient code output at 1180. If not, Diff is

decremented by one at 1170 and the differential DC coefficient is output at 1180. The process then continues at 1030 of Figure 10 to initialize the MPEG chip hardware for the re-encoding of the AC coefficients. Preferably, i is set to zero, RS and E1 are loaded from the packed intermediate format for the i th AC term and I is incremented. (It should be noted that steps 1030, 1035, and 1040, as will now be described, are specific to use of the preferred packed intermediate data format as incorporated by reference above. However, those skilled in the art will be able to practice the invention successfully, if not optimally, using data in other formats from an understanding of the data organization described above with reference to Figure 4 and the further detailed description in the above-incorporated patent application.) The data is then tested for an EOB (end-of-block) code which would indicate completion of coding at 1035. Assuming the re-encoding is not complete for the block, however, the process continues at 1040 which comprises a sequence of processes.

Specifically, step 1041 is optional if $Z=0$. If not, the run length is incremented as detailed in Figure 12. As shown in Figure 12, this process comprises testing for a ZRL at 1210 and, if so, the ZRL is evaluated, set and i is incremented at 1220. If there is no ZRL, the process is complete. In either case, the process resumes at 1042 of Figure 10 in which the run length is incremented by R , the JPEG size (S) is isolated and the extra bits (E1) indicated thereby. The variable "extra" is set to E1. Next, and optionally if $F=0$ (which indicates that S is always 8 or less), a check is made for an

E2 value in the intermediate data as detailed in Figure 13.

As illustrated in Figure 13, if the value of S, isolated above, indicates that there are more bits than fit within field E1 of the intermediate data, as determined at 1310, the number of extra bits is evaluated using E2 and the input index, i, is incremented as shown at 1320. This process to check for E2 is complete at this point either by step 1320 being performed or skipped from step 1310.

The process of Figure 10 then resumes at 1044, detailed in Figure 14A or 14B. The methodology of Figure 14A is preferred as providing the best entropy coding. However, the methodology of Figure 14B is much simpler albeit with some inefficiency in coding but which may, in general, may be adequate for image browsing or tolerable for achieving higher frequency image presentation while doing so. This latter methodology of Figure 14B is limited for simplicity to outputting fixed length codes for exceptions to the variable length code table 0 and 1 discussed above and thus may be considered as a subset of the method of Figure 14A and need not be further discussed.

In the better entropy coding methodology of Figure 14A, a test is first made to determine if a VLC is possible by testing for $S < 5$ and $\text{Run} < 16$ at 1410. If not, no VLC is possible and an exception is output at 1440, much as in the methodology of Figure 14B (e.g. the only execution speed penalty is for the test at 1410), a preferred method for which is detailed in Figure 16.

More specifically, it will be recalled that the MPEG VLC tables only reflect runs of fifteen or less

and size (number of extra bits) of four or less and only some of the run/level values which are in this range. Therefore, only if size, S, is four or less and the run is less than sixteen, is an effort made
5 to look up the VLC code. If so, then preferably, the lower order four bits from the JPEG extra bits are used to initialize the final index into the table as shown at 1410. Thus S - 1, shifted left by four bits becomes the next two bits in the index
10 calculation. In addition, the four bits of run are shifted left/up by six bits to complete the index calculation as shown at 1420. (This, of course, assumes that the table being indexed has an entry for every possible run/level in this range. Other
15 algorithms for calculating the index may be employed which are constructed to match table entries.) A variable, tem, is set to the result of looking up the VLC code at the computed index. If tem=0, as determined at 1425, no corresponding VLC code exists
20 in the table and the fixed length run and level codes following an escape code as done in 1440, a preferred technique for which is detailed in Figure 16. Otherwise the VLC code is output as shown at 1430, different alternative methods for which are
25 detailed in Figure 15A - 15C, as will now be discussed.

Figure 15A illustrates a basic method for outputting VLC codes. N, the number of bits in the VLC code (shown as left-justified in Table I and
30 converted to right-justification as shown in Figure 15A), is set from tem which frees tem for further use. Tem is then set to four bytes in which the least significant N bits are the VLC code. Then the N bits are output as a compressed data string as is

well-understood in the art.

Figure 15B illustrates a method for outputting VLC codes in a manner which allows reduction in storage requirements in the MPEG chip hardware and 5 may be necessary, for that reason, in chips having limited storage capacity. In other words, it can be shown that when the VLC code is right-justified, no more than nine bits will be non-zero and thus can be placed in two bytes with data indicating the number 10 of total bits in the remaining seven bits.

Specifically, Table IV below provides VLC 15 tables 0 and 1 corresponding to those provided in Table I, above but in which only the least significant nine bits need to be saved since higher order bits are always zero. The nine LSB could be saved in the high bits of two bytes and the low bits could be the number (nnnnn) of bits (e.g. two bits to seventeen bits) in the code (bbbb bbbb b..nnnnn).

20	Table IV run/level	vlc table 0	vlc table 1
25	0/0 (EOB)	.....10	.....0110
	0/1	.....11s	.....10s
	0/2	....0100s	....110s
	0/3	...00101s	...0111s
	0/4	.0000110s	..11100s
	0/5	00100110s	..11101s
	0/6	00100001s	..000101s
30	0/7	00 00001010s	..000100s
	0/8	0000 00011101s	.1111011s
	0/9	0000 00011000s	.1111100s
	0/10	0000 00010011s	00100011s
	0/11	0000 00010000s	00100010s
	0/12	00000 00011010s	11111010s
35	0/13	00000 00011001s	11111011s
	0/14	00000 00011000s	11111110s
	0/15	00000 00010111s	11111111s
	0/16	000000 00011111s	000000 00011111s
	0/17	000000 00011110s	000000 00011110s
40	0/18	000000 00011101s	000000 00011101s
	0/19	000000 00011100s	000000 00011100s
	0/20	000000 00011011s	000000 00011011s
	0/21	000000 00011010s	000000 00011010s

	0/22	000000 00011001s	000000 00011001s
	0/23	000000 00011000s	000000 00011000s
	0/24	000000 00010111s	000000 00010111s
	0/25	000000 00010110s	000000 00010110s
5	0/26	000000 00010101s	000000 00010101s
	0/27	000000 00010100s	000000 00010100s
	0/28	000000 00010011s	000000 00010011s
	0/29	000000 00010010s	000000 00010010s
	0/30	000000 00010001s	000000 00010001s
10	0/31	000000 00010000s	000000 00010000s
	0/32	0000000 00011000s	0000000 00011000s
	0/33	0000000 00010111s	0000000 00010111s
	0/34	0000000 00010110s	0000000 00010110s
	0/35	0000000 00010101s	0000000 00010101s
15	0/36	0000000 00010100s	0000000 00010100s
	0/37	0000000 00010011s	0000000 00010011s
	0/38	0000000 00010010s	0000000 00010010s
	0/39	0000000 00010001s	0000000 00010001s
	0/40	0000000 00010000s	0000000 00010000s
20	1/1	.....011s	.....010s
	1/2	.000110s	..00110s
	1/3	00100101s	.1111001s
	1/4	00 00001100s	00100111s
	1/5	0000 00011011s	00100000s
25	1/6	00000 00010110s	00000 00010110s
	1/7	00000 00010101s	00000 00010101s
	1/8	0000000 00011111s	0000000 00011111s
	1/9	0000000 00011110s	0000000 00011110s
	1/10	0000000 00011101s	0000000 00011101s
30	1/11	0000000 00011100s	0000000 00011100s
	1/12	0000000 00011011s	0000000 00011011s
	1/13	0000000 00011010s	0000000 00011010s
	1/14	0000000 00011001s	0000000 00011001s
	1/15	00000000 00010011s	00000000 00010011s
35	1/16	00000000 00010010s	00000000 00010010s
	1/17	00000000 00010001s	00000000 00010001s
	1/18	00000000 00010000s	00000000 00010000s
	2/1	....0101s	...00101s
	2/2	.0000100s	.0000111s
40	2/3	00 00001011s	11111100s
	2/4	0000 00010100s	00 00001100s
	2/5	00000 00010100s	00000 00010100s
	3/1	...00111s	..00111s
	3/2	00100100s	00100110s
45	3/3	0000 00011100s	0000 00011100s
	3/4	00000 00010011s	00000 00010011s
	4/1	...00110s	..000110s
	4/2	00 00001111s	11111101s
	4/3	0000 00010010s	0000 00010010s
50	5/1	..0000111s	..0000111s
	5/2	00 00001001s	0 00000100s
	5/3	00000 00010010s	00000 00010010s
	6/1	..0000101s	.0000110s
	6/2	0000 00011110s	0000 00011110s
55	6/3	00000000 00010100s	00000000 00010100s
	7/1	.0000100s	.0000100s
	7/2	0000 00010101s	0000 00010101s
	8/1	.00000111s	.0000101s
	8/2	0000 00010001s	0000 00010001s
60	9/1	.00000101s	.1111000s

	9/2	00000 00010001s	00000 00010001s
	10/1	00100111s	.1111010s
	10/2	00000 00010000s	00000 00010000s
	11/1	00100011s	00100001s
5	11/2	00000000 00011010s	00000000 00011010s
	12/1	00100010s	00100101s
	12/2	00000000 00011001s	00000000 00011001s
	13/1	00100000s	00100100s
	13/2	00000000 00011000s	00000000 00011000s
10	14/1	00 00001110s	0 00000101s
	14/2	00000000 00010111s	00000000 00010111s
	15/1	00 00001101s	0 00000111s
	15/2	00000000 00010110s	00000000 00010110s
	16/1	00 00001000s	00 00001101s
15	16/2	00000000 00010101s	00000000 00010101s
	17/1	0000 00011111s	0000 00011111s
	18/1	0000 00011010s	0000 00011010s
	19/1	0000 00011001s	0000 00011001s
	20/1	0000 00010111s	0000 00010111s
20	21/1	0000 00010110s	0000 00010110s
	22/1	00000 00011111s	00000 00011111s
	23/1	00000 00011110s	00000 00011110s
	24/1	00000 00011101s	00000 00011101s
	25/1	00000 00011100s	00000 00011100s
25	26/1	00000 00011011s	00000 00011011s
	27/1	00000000 00011111s	00000000 00011111s
	28/1	00000000 00011110s	00000000 00011110s
	29/1	00000000 00011101s	00000000 00011101s
	30/1	00000000 00011100s	00000000 00011100s
30	31/1	00000000 00011011s	00000000 00011011s

Figure 15C illustrates an alternative technique of outputting VLC codes providing convenience of storage of VLC/Huffman codes. In other words, the VLC codes can be split into a segment which always ends with the left-most "1" in the code and the remaining bits to the right of the left-most "1" are thus guaranteed to fit in a single byte (eight bits).

Table V, below shows how the high byte could have the number of leading zeros in the high four bits and the number of remaining bits in the low four bits (zzzz nnnn) The second byte includes the bits following the first 1. The bits designated '.' can either be in the most significant or least significant bits depending upon how the code is stored in the table.

zeros and first leading 1 generated separately.

Another table stores the number of leading zeros and number of valid bits in the byte (zzzz nnnn).

	run/level	vlc table 0	vlc table 1
5	0/0	1 0.....	01 10.....
	0/1	1 1s.....	1 0s.....
	0/2	01 00s.....	1 10s.....
	0/3	001 01s.....	01 11s.....
10	0/4	00001 10s.....	1 1100s...
	0/5	001 00110s..	1 1101s...
	0/6	001 00001s..	0001 01s.....
	0/7	0000001 010s....	0001 00s.....
	0/8	00000001 1101s...	1 111011s.
15	0/9	00000001 1000s...	1 111100s.
	0/10	00000001 0011s...	001 00011s..
	0/11	00000001 0000s...	001 00010s..
	0/12	0 00000001 1010s...	1 1111010s
	0/13	0 00000001 1001s...	1 1111011s
20	0/14	0 00000001 1000s...	1 1111110s
	0/15	0 00000001 0111s...	1 1111111s
	0/16	00 00000001 1111s...	00 00000001 1111s...
	0/17	00 00000001 1110s...	00 00000001 1110s...
	0/18	00 00000001 1101s...	00 00000001 1101s...
25	0/19	00 00000001 1100s...	00 00000001 1100s...
	0/20	00 00000001 1011s...	00 00000001 1011s...
	0/21	00 00000001 1010s...	00 00000001 1010s...
	0/22	00 00000001 1001s...	00 00000001 1001s...
	0/23	00 00000001 1000s...	00 00000001 1000s...
30	0/24	00 00000001 0111s...	00 00000001 0111s...
	0/25	00 00000001 0110s...	00 00000001 0110s...
	0/26	00 00000001 0101s...	00 00000001 0101s...
	0/27	00 00000001 0100s...	00 00000001 0100s...
	0/28	00 00000001 0011s...	00 00000001 0011s...
35	0/29	00 00000001 0010s...	00 00000001 0010s...
	0/30	00 00000001 0001s...	00 00000001 0001s...
	0/31	00 00000001 0000s...	00 00000001 0000s...
	0/32	000 00000001 1000s...	000 00000001 1000s...
	0/33	000 00000001 0111s...	000 00000001 0111s...
40	0/34	000 00000001 0110s...	000 00000001 0110s...
	0/35	000 00000001 0101s...	000 00000001 0101s...
	0/36	000 00000001 0100s...	000 00000001 0100s...
	0/37	000 00000001 0011s...	000 00000001 0011s...
	0/38	000 00000001 0010s...	000 00000001 0010s...
45	0/39	000 00000001 0001s...	000 00000001 0001s...
	0/40	000 00000001 0000s...	000 00000001 0000s...
	1/1	01 1s.....	01 0s.....
	1/2	0001 10s.....	001 10s.....
	1/3	001 00101s..	1 111001s.
50	1/U	0000001 100s ...	001 00111s..
	1/5	00000001 1011s...	001 00000s..
	1/6	0 00000001 0110s...	0 00000001 0110s...
	1/7	0 00000001 0101s...	0 00000001 0101s...
	1/8	000 00000001 1111s...	000 00000001 1111s...
	1/9	000 00000001 1110s...	000 00000001 1110s...

5	1/10	000 00000001	1101s...	000 00000001	1101s...		
	1/11	000 00000001	1100s...	000 00000001	1100s...		
	1/12	000 00000001	1011s...	000 00000001	1011s...		
	1/13	000 00000001	1010s...	000 00000001	1010s...		
5	1/14	000 00000001	1001s...	000 00000001	1001s...		
	1/15	0000 00000001	0011s...	0000 00000001	0011s...		
	1/16	0000 00000001	0010s...	0000 00000001	0010s...		
	1/17	0000 00000001	0001s...	0000 00000001	0001s...		
	1/18	0000 00000001	0000s...	0000 00000001	0000s...		
10	2/1	01	01s.....	001	01s.....		
	2/2	00001	00s.....	00001	11s.....		
	2/3	0000001	011s.....	1	1111100s		
	2/4	00000001	0100s...	00000001	100s....		
15	2/5	0	00000001	0100s...	0	00000001	0100s...
	3/1	001	11s.....	001	11s.....		
	3/2	001	00100s..	001	00110s..		
	3/3	00000001	1100s...	00000001	1100s...		
	3/4	0	00000001	0011s...	0	00000001	0011s...
20	4/1	001	10s.....	0001	10s.....		
	4/2	00000001	111s....	1	1111101s		
	4/3	00000001	0010s...	00000001	0010s...		
	5/1	0001	11s.....	0001	11s.....		
	5/2	00000001	001s....	00000001	00s....		
25	5/3	0	00000001	0010s...	0	00000001	0010s...
	6/1	0001	01s.....	00001	10s.....		
	6/2	00000001	1110s...	00000001	1110s...		
	6/3	0000	00000001	0100s...	0000	00000001	0100s...
	7/1	0001	00s.....	00001	00s.....		
30	7/U	00000001	0101s...	00000001	0101s...		
	8/1	00001	11s.....	00001	01s.....		
	8/2	00000001	0001s...	00000001	0001s...		
	9/1	00001	01s.....	1	111000s.		
	9/2	0	00000001	0001s...	0	00000001	0001s...
35	10/1	001	00111s..	1	111010s.		
	10/2	0	00000001	0000s...	0	00000001	0000s...
	11/1	001	00011s..	001	00001s..		
	11/2	0000	00000001	1010s...	0000	00000001	1010s...
40	12/1	001	00010s..	001	00101s..		
	12/2	0000	00000001	1001s...	0000	00000001	1001s...
	13/1	001	00000s..	001	00100s..		
	13/2	0000	00000001	1000s...	0000	00000001	1000s...
	14/1	0000001	110s....	0000001	01s....		
	14/2	0000	00000001	0111s...	0000	00000001	0111s...
45	15/1	00000001	101s....	00000001	11s....		
	15/2	0000	00000001	0110s...	0000	00000001	0110s...
	16/1	0000001	000s....	0000001	101s....		
	16/2	0000	00000001	0101s...	0000	00000001	0101s...
	17/1	00000001	1111s...	00000001	1111s...		
50	18/1	00000001	1010s...	00000001	1010s...		
	19/1	00000001	1001s...	00000001	1001s...		
	20/1	00000001	0111s...	00000001	0111s...		
	21/1	00000001	0110s...	00000001	0110s...		
	22/1	0	00000001	1111s...	0	00000001	1111s...
55	23/1	0	00000001	1110s...	0	00000001	1110s...
	24/1	0	00000001	1101s...	0	00000001	1101s...
	25/1	0	00000001	1100s...	0	00000001	1100s...
	26/1	0	00000001	1011s...	0	00000001	1011s...
	27/1	0000	00000001	1111s...	0000	00000001	1111s...
	28/1	0000	00000001	1110s...	0000	00000001	1110s...
60	29/1	0000	00000001	1101s...	0000	00000001	1101s...

```
30/1 0000 00000001 1100s... 0000 00000001 1100s...
31/1 0000 00000001 1011s... 0000 00000001 1011s...
```

It should be note that except for the 0/0 run/level, the EOB code and the escape code, the
5 sign bit "s" could be removed so that the non-zero
bits could always be fit into an eight-bit byte;
yielding additional savings in storage space for the
VLC tables as shown in Table V. This potentially
allows additional storage space to be provided on a
10 given MPEG chip for image data (e.g. for
particularly large images).

It should be observed that the Huffman/VLC
lookup tables can be significantly reduced by
observing that all runs greater than 15 must have
15 gone through the ZRL path. Once in that path the
next non-zero coefficient could be handled with
special cases only for S=1 & R<32 and S=2 & R=16
instead of up to S=4. This would cut the tables on
the non-ZRL path in half.

20 Figure 16 illustrates a preferred technique for
outputting exceptions as a fixed length code as part
of the above-discussed routines of Figures 14A and
14B. The first step is to convert the extra bits
(e.g. the JPEG coefficient value represented by the
25 size and extra bits) to the appropriate MPEG level,
preferably as detailed in Figure 17. The next step
is to output the fixed six-bit escape code.
Finally, the run is output in six bits followed by
the level which is output in twelve bits.

30 Figure 17 illustrates a preferred technique for
converting the JPEG extra bits into the MPEG level.
Assuming that the extra bits are right-justified,
then S-1 shifts to the right will position the first
significant bit of the extra bits in the least

significant bit position where it can be tested. If the tested bit is zero, the number is negative and sign bits must be ORed in to the higher order bits. This is done by shifting -1 to the left by S bits 5 and then ORing in to the extra bits number. Adding +1 converts it into the true negative number. Then "level" is set to "extra" in all cases. Optionally, the range can be checked as shown in Figure 18A or 10 18B. In JPEG, a level of -2048 is possible and should be tested in order to reset it to the largest negative number permitted in MPEG (-2047) as shown in Figure 18A. Alternatively, both positive and negative levels can be checked to confirm that they are in the range of -2047 to +2047 as shown in 15 Figure 18B.

In view of the foregoing, it is seen that the invention provides a technique for exploiting the MPEG hardware chip speed for browsing JPEG images. The software JPEG processing load is reduced by at 20 least half during transcoding by transfer of processing to the hardware MPEG chip. The hardware MPEG chip runs autonomously with little interaction with the processor and in parallel with the processor and, as specialized hardware, at 25 accelerated processing speed. Thus high image presentation rates and/or image sizes for independent images can be achieved even when limited by (reduced) JPEG software processing, while improvements in general purpose processors which can be foreseen will thus allow a fourfold to tenfold or 30 greater processing speed gain, corresponding to the current hardware speed advantage over software.

Similarly, an MPEG encoder could be used to process high-resolution still images and later,

within the embedded processor, converted to JPEG compliant data. It would be highly desirable, in such a case, to have disabled the oddification. Further, in such a case, the quantization tables being JPEG compliant, no rescaling would be required. Such an application is particularly likely in view of the current proliferation of chips having both encoders and decoders which are MPEG compliant, as distinguished from chips having both JPEG and MPEG compliant capabilities; requiring more chip space and unavoidable additional cost.

Furthermore, the MPEG motion compensation and P-frame predictive capability may allow additional chip space and unavoidable additional cost. Furthermore, the MPEG motion compensation and desirable compression, especially for large images with substantial redundancy, allowing limitation of resolution loss. That is, if the distortion is too great, a macroblock can always be encoded independently within a portion of the image using the MPEG I-frame method. By the same token, if the browsing is stopped on an image, the correct JPEG image data can be derived from conventional JPEG software techniques and substituted for the MPEG-decoded image data for display or even in memory before or after a browsed image or portion thereof is viewed. For example, data could be substituted in memory before or after display for respective tiles of a map which may be later recalled in a desired combination for zooming or panning simulation display (e.g. in a video game) whether or not browsing is stopped on an image.

When the JPEG compressed high resolution image has many more pixels than can be shown at once on the output device, browsing within the image (i.e. panning, scrolling and combinations resulting in

oblique motion) generates known translations which are represented by coordinates from which motion vectors can be easily derived. These can be converted into MPEG motion vectors without using the motion estimation hardware so that only the incremental portion of the JPEG image need be compressed. The portion already in the previous decoded frame is a perfect prediction particularly if the motion vectors are restricted to multiples of 8 translations vertically and horizontally (i.e. the 8x8 block boundaries). Thus the new parts of the image match the original JPEG block boundaries for rapid browsing within an image. Since the JPEG compressed data is only partially decoded (e.g. entropy decoded), the uncompressed data of the new frame is not available for the motion estimation hardware. For slower browsing within an image, fewer blocks of the JPEG image are newly exposed so that the JPEG block boundaries can be shifted to generate packed format to match pixel or even sub-pixel shifts. These types of shifts can be accomplished by, for example, the technique described in U. S. Patent Application 09/588,477 which is assigned to the assignee of the present application and hereby fully incorporated by reference. Such browsing would be particularly useful for wireless telephones (e.g. "cell phones") and other small displays or for video games that restrict the field of view.

While the invention has been described in terms of a single preferred embodiment having variant forms, those skilled in the art will recognize that the invention can be practiced with modification within the spirit and scope of the appended claims.